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Flow reattachment point detection via thermal sensors - PIV evaluation

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Abstract

Recent advances in flow control have the potential for significant impact on the engineering design. Fluidic flow control is a method for altering flows over aerodynamic surfaces which does not rely upon altering the physical shape of the surface (typically through moving control surfaces such as flaps). The steady air flow along a basic geometry of a backward facing step is used to study the alterations of the resulting recirculation area ether spontaneously or by applying pulsating fluid injection below the edge of the step as control actuator. The PIV method is used to monitor the velocity field and determine the reattachment point. Applying flow sensors based on hot wire anemometry on the bottom wall boundary it is possible to estimate parameters such as the recirculation length or even the region of intense turbulent activity as compared and verified by the PIV. Preliminary measurements by thermal sensors reveals fingerprints of the reattachment zone applying time-frequency analysis.

Keywords: PIV; thermal sensor; turbulence; backward facing step.

1. Introduction

The recent interest of fluid dynamicists with regard to either active or passive flow control is due to its significant contribution to efficiency improvement of various fluid exposed mechanical components with a small energy cost. In this context, problems related with flow instabilities triggered by external perturbations has motivated mathematicians and engineers to provide solutions on a theoretical and practical basis. Small-scale fluid ejection can leverage small-scale control inputs to have large-scale effects of the flows, with applications including altering the lift and drag of an aerodynamic surface, enhancing mixing, or altering the direction of existing flows. Steady blowing or suction has been used for decades as a means of accomplishing this, although in recent years implementations have moved on to active flow control which uses unsteady excitation to manipulate the flow more efficiently.

2. Experimental setup and results

The turbulent flow field of a backward facing step is experimentally studied in an open circuit wind tunnel. Figure 1a demonstrates the first of three sequent domains analyzed by the PIV covering the

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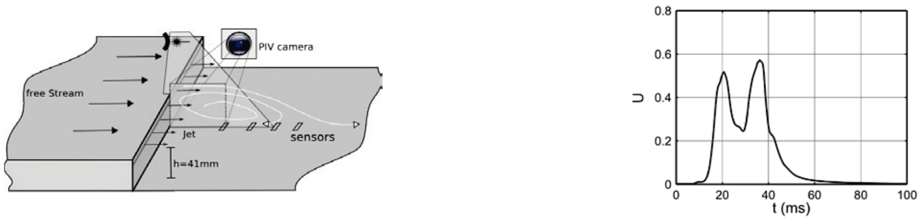
sensor was used in nine different positions in the streamwise direction to estimate the instant local velocity gradient. The sampling rate of choice was 1kHz that is considered sufficient compared to the bandwidth of the velocity flactuation. A hot wire sensor was used to measure the velocity 1cm away from the jet output as a function of time (fig. 1b). The free stream velocity is set 4 times the jet velocity that is about 2.5m/s.



(a) (b)

Fig. 1. (a) The model of backward facing step. Jet actuator and PIV setup. (b). Velocity profile of jet actuator

In the frame of evaluation of the sensor response as well as of the circuity developed we only take single point measurements without the jet actuator in action. On the contrary, the velocity field on the midplane is extracted using a 2-D Particle Image Velocimetry system (PIV) [1] for both unforced case and many forced cases employing a number of pulsating air jets as a means for reduction of the length of the recirculation zone (Fig.1a). The frequency of the jets was controlled via an electric vane which opened and closed periodically allowing the air from an air chamber to flow to the step.

Summarizing, the active flow control consists of applying periodically pulsating air jets, triggering a 2-D Particle Image Velocimetry system and making A/D conversion of the thermal sensor response. The used framework is based on Real Time Application Interface [2] (RTAI) which is an ideal platform for rapid prototyping of control systems and simulations in real time. The latency measured on the used setup is ~10μs. The simulation model developed controls specially constructed signal conditioning circuits that drive low cost thermal sensors and stores the recordings, it precisely controls the on-off state of the electric vane and also it triggers the PIV procedure.

Figure 2 shows the velocity field of forced case using the jet pulsation of fig.1b as well the one of the unforced case. The recirculation length is reduced by about 24% when forced by a 10 Hz frequency of pulsation [3].

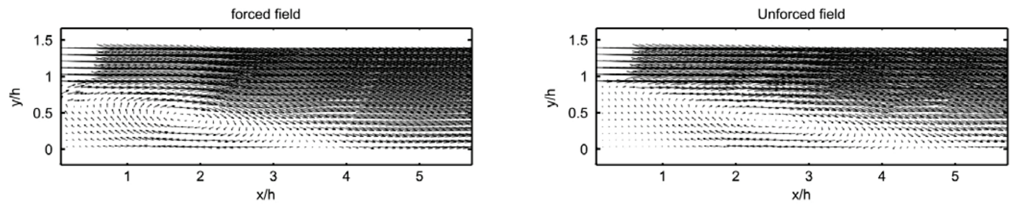


Fig. 2. Mean velocity field of unforced flow (left) and forced flow (right)

Holding the jet pulse unchanged while varying the repetition frequency we are able to determine the corresponding reattachment points for 25 cases shown in figure 3.

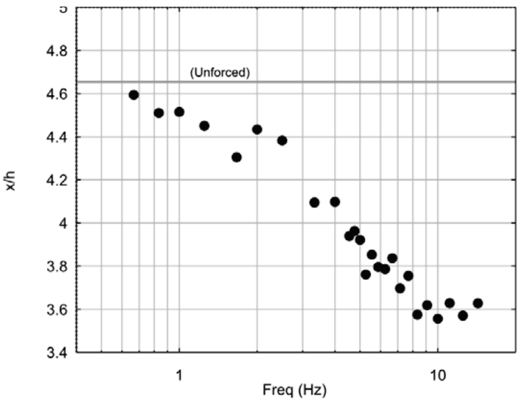


Fig. 3. Recirculation length vs actuation Frequency

Although the used PIV system provides a good picture of the flow, it is not fast enough for real time flow control and it is not adaptive to real world applications. The hot film flow sensor is of course more applicable. The streamwise velocity changes sign at the reattachment point expecting a minimum of the field in the neighbor. This effect is also observed ether from the independent set of calculated fields from PIV or from the timeseries taken by the hot film sensor. Figure 3 shows the similar pattern of mean velocity versus the recirculation length L.

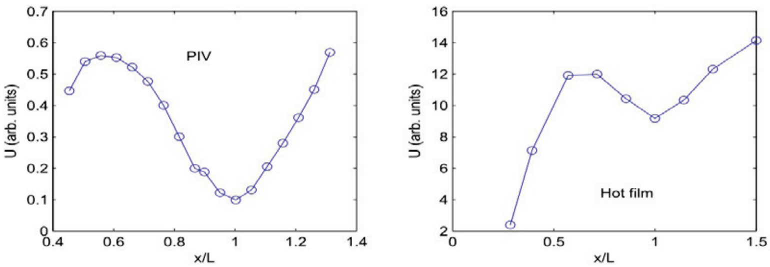


Fig. 4.Mean velocity vs recirculation length as estimated from PIV (left) and thermal sensor (right).

Penetrating more in the flow characteristics we can summarize the complex turbulent activity by mapping the “turbulent kinetic Energy”. The high values represent areas of high velocity fluctuation. Figure 5 shows that from 0.6L to 1.2L the turbulent activity occurs close to the bottom wall boundary.

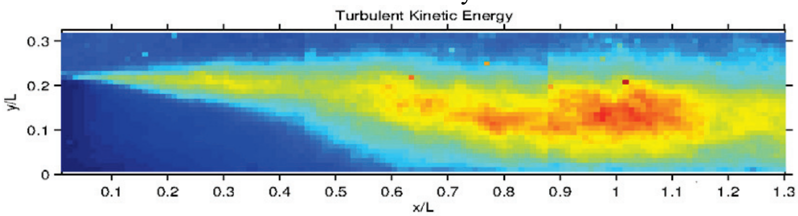


Fig. 5. Turbulent Kinetic Energy of unforced flow

basic time-frequency analysis based on “spectrogram” (fig.6) shows that x=0.3L and x=0.4L where turbulent activity near the wall is week the recordings are broadband without any oscillatory behavior similar to colored noise. On the contrary just before and after the reattachment point the recordings are narrow band with oscillations between 100 and 200Hz. At the reattachment point these oscillations are missing.

3. Conclusions

The above preliminary analysis shows that it is possible to detect the reattachment point even in real time using hot film sensors on the wall boundary. Further optimizations and synchronized recordings from a grid of sensors promises enough information for real-time flow control system.

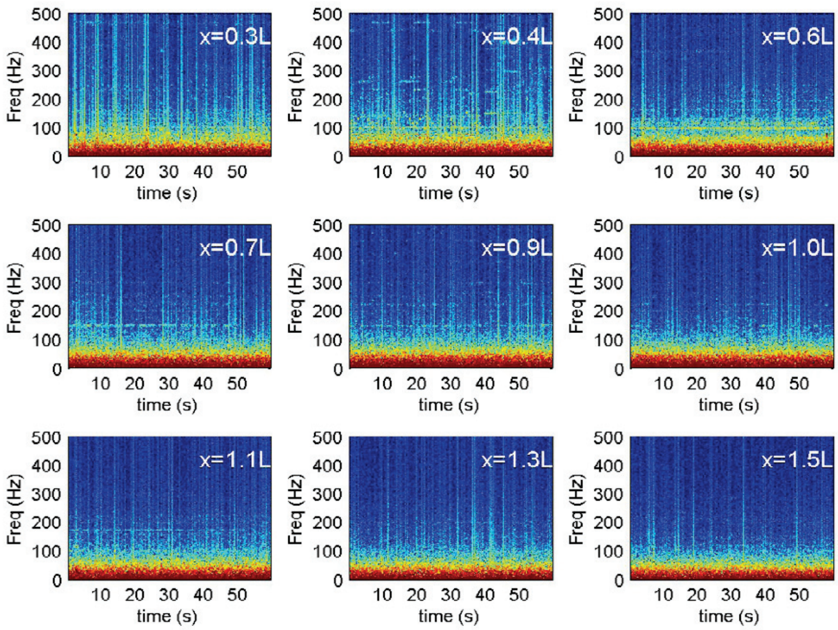


Fig. 6.Time-frequency analysis of recordings from thermal sensor at various positions.

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